Furthermore, in some embodiments, controller **1230** can cause beam focusing assembly **1214** to scan the write beam over a region of the substrate, *e.g.*, using signal **1244**. As a result, controller **1230** directs the other components of the system to pattern the substrate. The patterning is typically based on an electronic design pattern stored in the controller. In some applications the write beam patterns a resist coated on the substrate and in other applications the write beam directly patterns, *e.g.*, etches, the substrate.

An important application of such a system is the fabrication of masks and reticles used in the lithography methods described previously. For example, to fabricate a lithography mask an electron beam can be used to pattern a chromium-coated glass substrate. In such cases where the write beam is an electron beam, the beam writing system encloses the electron beam path in a vacuum. Also, in cases where the write beam is, *e.g.*, an electron or ion beam, the beam focusing assembly includes electric field generators such as quadrapole lenses for focusing and directing the charged particles onto the substrate under vacuum. In other cases where the write beam is a radiation beam, *e.g.*, x-ray, UV, or visible radiation, the beam focusing assembly includes corresponding optics and for focusing and directing the radiation to the substrate.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method comprising:

providing an interference signal $S(t)$ from two beams derived from a common source and directed along different paths, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths, where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, and t is time;

providing coefficients representative of one or more errors that cause the signal $S(t)$ to deviate from an ideal expression of the form $A_1 \cos\left(\omega_R t + \varphi(t) + \zeta_1\right)$, where A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams;

calculating a quadrature signal $\tilde{S}(t)$ based on the signal $S(t)$; and

reducing the deviation of $S(t)$ from the ideal expression using an error signal $S_\psi(t)$ generated from the coefficients and error basis functions derived from the signals $S(t)$ and $\tilde{S}(t)$.

2. The method of claim 1, further comprising directing the two beams along the different paths and measuring the interference signal $S(t)$.

3. The method of claim 2, wherein at least one of the beams is directed to reflect from a movable measurement object before producing the interference signal $S(t)$.

4. The method of claim 3, wherein the beam directed to contact the movable measurement object reflects from the measurement object multiple times before producing the interference signal $S(t)$.

5. The method of claim 3, wherein the beams are directed to reflect from different locations of the movable measurement object before producing the interference signal $S(t)$.

6. The method of claim 1, wherein the errors correspond to spurious beam paths.

7. The method of claim 1, wherein the deviation can be expressed as $\sum_{m,p} A_{m,p} \cos\left(\omega_R t + \frac{m}{p}\varphi(t) + \zeta_{m,p}\right)$, where p=1, 2, 3..., and m is any integer not equal to p, and where the provided coefficients comprise information corresponding to at least some of $A_{m,p}$ and $\zeta_{m,p}$.

8. The method of claim 1, wherein ω_R is non-zero.

9. The method of claim 8, further comprising:

providing a reference signal $S_R(t) = A_R \cos(\omega_R t + \zeta_R)$, where A_R and ζ_R are constants; and

calculating a quadrature reference signal $\tilde{S}_R(t)$ based on the signal $S_R(t)$,

wherein the error basis functions are derived from the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

10. The method of claim 9, further comprising measuring the reference signal $S_R(t)$ based on an output from the common source.

11. The method of claim 1, wherein calculating the quadrature signal $\tilde{S}(t)$ comprises calculating the quadrature signal $\tilde{S}(t)$ based on the expression $\tilde{S}(t) = (\cot\omega_M\tau)S(t-2\tau) - \frac{\cos 2\omega_M\tau}{\sin\omega_M\tau}S(t-\tau)$, where τ >0 and ω_M is an instantaneous rate of change of a phase of the interference signal $S(t)$.

12. The method of claim 11, wherein calculating the quadrature signal $\tilde{S}(t)$ further comprises approximating ω_M according to $\omega_M \approx \omega_R + d\varphi(t)/dt$, where $\varphi(t)$ in the expression for ω_M is determined from the interference signal $S(t)$ assuming the deviation of $S(t)$ from the ideal expression is negligible.

13. The method of claim 11, wherein calculating the quadrature signal $\tilde{S}(t)$ further comprises approximating ω_M according to $\omega_M \approx \omega_R$.

14. The method of claim 13, wherein calculating the quadrature signal $\tilde{S}(t)$ comprises calculating the quadrature signal $\tilde{S}(t)$ according to the simplified expression $\tilde{S}(t) = \frac{1}{\sqrt{3}}\left[S(t-\tau)+S(t-2\tau)\right]$ for $\tau = (\pi + 6\pi N)/3\omega_R$, where N is a non-negative integer.

15. The method of claim 9, wherein calculating the quadrature reference signal $\tilde{S}_R(t)$ comprises calculating the quadrature reference signal $\tilde{S}_R(t)$ based on the expression $\tilde{S}_R(t) = (\cot \omega_R\tau) S_R(t-2\tau) - \frac{\cos 2\omega_R\tau}{\sin \omega_R\tau} S_R(t-\tau)$, where $\tau > 0$.

16. The method of claim 15, wherein calculating the quadrature reference signal $\tilde{S}_R(t)$ comprises calculating the quadrature reference signal $\tilde{S}_R(t)$ according to the simplified expression $\tilde{S}_R(t) = \frac{1}{\sqrt{3}}\left[S_R(t-\tau)+S_R(t-2\tau)\right]$ for $\tau = (\pi + 6\pi N)/3\omega_R$, where N is a non-negative integer.

17. The method of claim 1, wherein the interference signal $S(t)$ is provided at a data rate that is an integer multiple of $\omega_R/2\pi$.

18. The method of claim 1, wherein the error basis functions correspond to one or more pairs of sine and cosine functions having an argument whose time-varying component has the form $\omega_R t + (m/p)\varphi(t)$, where p is a positive integer and m is an integer not equal to p.

19. The method of claim 18, wherein the error basis functions correspond to multiple pairs of the sine and cosine functions.

20. The method of claim 19, wherein the error basis functions comprise multiple pairs of the sine and cosine functions from a family of the sine and cosine functions with $\{(p=1,m=-1),(p=1,m=0),(p=1,m=2),(p=1,m=3), and\,(p=2,m=1)\}$.

21. The method of claim 1, further comprising generating the error basis functions from the signals $S(t)$ and $\tilde{S}(t)$.

22. The method of claim 9, further comprising generating the error basis functions from the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

23. The method of claim 22, wherein the error basis functions are generated from algebraic combinations of the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

24. The method of claim 1, further comprising generating the error signal $S_\psi(t)$.

25. The method of claim 24, the error signal $S_\psi(t)$ is generated from a superposition of the error basis functions weighted by the coefficients representative of the errors.

26. The method of claim 1, wherein reducing the deviation comprises subtracting the error signal $S_\psi(t)$ from the interference signal $S(t)$.

27. The method of claim 1, further comprising determining a value for the optical path difference $n\tilde{L}(t)$ from the interference signal $S(t)$ after its deviations are reduced.

28. The method of claim 1, wherein the quadrature signal $\tilde{S}(t)$ is calculated from the interference signal $S(t)$ based on prior values of $S(t)$ according to the approximation $S(t) \approx S(t - 2\pi N/\omega_R)$, where N is a positive integer.

29. The method of claim 1, wherein the error basis functions used to generate the error signal $S_\psi(t)$ are derived from prior values of the signals $S(t)$ and $\tilde{S}(t)$ according to the approximations $S(t) \approx S(t - 2\pi N/\omega_R)$ and $\tilde{S}(t) \approx \tilde{S}(t - 2\pi M/\omega_R)$, where N and M are positive integers.

30. The method of claim 1, wherein $\omega_R > 100 \cdot d\varphi(t)/dt$.

31. The method of claim 1, wherein $\omega_R > 500 \cdot d\varphi(t)/dt$.

32. A method comprising:

providing an interference signal $S(t)$ from two beams derived from a common source and directed along different paths, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths, where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, and t is time;

providing coefficients representative of one or more errors that cause the signal $S(t)$ to deviate from an ideal expression of the form $A_1 \cos(\omega_R t + \varphi(t) + \zeta_1)$, where A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams; and

reducing the deviation of $S(t)$ from the ideal expression using an error signal $S_\psi(t)$ generated from the coefficients and error basis functions derived from the interference signal $S(t)$ based on prior values of $S(t)$ according to the approximation $S(t) \approx S(t - 2\pi N/\omega_R)$, where N is a positive integer.

33. The method of claim 32, wherein $\omega_R > 100 \cdot d\varphi(t)/dt$.

34. The method of claim 32, further comprising providing a reference signal $S_R(t) = A_R \cos(\omega_R t + \zeta_R)$, where ω_R is non-zero and A_R and ζ_R are constants, and wherein the error basis functions are derived from the signals $S(t)$ and $S_R(t)$.

35. The method of claim 34, wherein the derivation of the error basis functions is based on prior values of $S_R(t)$ according to $S_R(t) = S_R(t - 2\pi M/\omega_R)$, where M is a positive integer.

36. A method for estimating coefficients representative of one or more errors that cause an interference signal $S(t)$ from two beams derived from a common source and directed along different paths to deviate from an ideal expression of the form $A_1 \cos(\omega_R t + \varphi(t) + \zeta_1)$, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths,

where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, t is time, A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams,

the method comprising:

calculating a quadrature signal $\tilde{S}(t)$ based on the signal $S(t)$; and

calculating an estimate for the coefficients based on the signals $S(t)$ and $\tilde{S}(t)$.

37. The method of claim 36, further comprising:

providing a reference signal $S_R(t) = A_R \cos(\omega_R t + \zeta_R)$, where ω_R is non-zero and A_R and ζ_R are constants; and

calculating a quadrature reference signal $\tilde{S}_R(t)$ based on the signal $S_R(t)$,

wherein the estimate for the coefficients is based on the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

38. The method of claim 36, wherein calculating the estimate for the coefficients comprises generating error basis functions derived from the signals $S(t)$ and $\tilde{S}(t)$.

39. The method of claim 37, wherein calculating the estimate for the coefficients comprises generating error basis functions derived from the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

40. The method of claim 39, wherein the error basis functions correspond to one or more pairs of sine and cosine functions having an argument whose time-varying component has the form $\omega_R t + (m/p)\varphi(t)$, where *p* is a positive integer and *m* is an integer not equal to *p*.

41. The method of claim 40, wherein the error basis functions are generated from algebraic combinations of the signals $S(t)$, $\tilde{S}(t)$, $S_R(t)$, and $\tilde{S}_R(t)$.

42. The method of claim 40, wherein the error basis functions correspond to multiple pairs of the sine and cosine functions.

43. The method of claim 42, wherein the error basis functions comprise multiple pairs of the sine and cosine functions from a family of the sine and cosine functions with $\{(p=1,m=-1),(p=1,m=0),(p=1,m=2),(p=1,m=3), and\,(p=2,m=1)\}$.

44. The method of claim 38, wherein calculating the estimate for the coefficients comprises low-pass filtering algebraic combinations of the error basis functions and the signals $S(t)$ and $\tilde{S}(t)$.

45. The method of claim 39, wherein calculating the estimate for the coefficients comprises low-pass filtering algebraic combinations of the error basis functions and the signals $S(t)$ and $\tilde{S}(t)$.

46. The method of claim 44, wherein the low-pass filtering comprises using a Butterworth filter.

47. The method of claim 45, wherein the low-pass filtering comprises using a Butterworth filter.

48. An apparatus comprising a computer readable medium which during operation causes a processor to perform the method of claim 1.

49. An apparatus comprising a computer readable medium which during operation causes a processor to perform the method of claim 32.

50. An apparatus comprising a computer readable medium which during operation causes a processor to perform the method of claim 36.

51. An apparatus comprising:

an interferometry system which during operation directs two beams derived from a common source along different paths and provides an interference signal $S(t)$ from the two

beams, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths, where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, and t is time,

wherein imperfections in the interferometry system produce one or more errors that cause the signal $S(t)$ to deviate from an ideal expression of the form $A_1 \cos(\omega_R t + \varphi(t) + \zeta_1)$, where A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams; and

an electronic processor which during operation receives the interference signal $S(t)$ from the interferometry system, receives coefficients representative of the one or more errors, calculates a quadrature signal $\tilde{S}(t)$ based on the signal $S(t)$, and reduces the deviation of $S(t)$ from the ideal expression using an error signal $S_\psi(t)$ generated from the coefficients and error basis functions derived from the signals $S(t)$ and $\tilde{S}(t)$.

52. An apparatus comprising:

an interferometry system which during operation directs two beams derived from a common source along different paths and provides an interference signal $S(t)$ from the two beams, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths, where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, and t is time,

wherein imperfections in the interferometry system produce one or more errors that cause the signal $S(t)$ to deviate from an ideal expression of the form $A_1 \cos(\omega_R t + \varphi(t) + \zeta_1)$, where A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams; and

an electronic processor which during operation receives the interference signal $S(t)$ from the interferometry system, receives coefficients representative of the one or more errors, and reduces the deviation of $S(t)$ from the ideal expression using an error signal $S_{\psi}(t)$ generated from the coefficients and error basis functions derived from the interference signal $S(t)$ based on prior values of $S(t)$ according to the approximation $S(t) \approx S(t - 2\pi N/\omega_R)$, where N is a positive integer.

53. An apparatus comprising:

an interferometry system which during operation directs two beams derived from a common source along different paths and provides an interference signal $S(t)$ from the two beams, wherein the signal $S(t)$ is indicative of changes in an optical path difference $n\tilde{L}(t)$ between the different paths, where n is an average refractive index along the different paths, $\tilde{L}(t)$ is a total physical path difference between the different paths, and t is time,

wherein imperfections in the interferometry system produce one or more errors that cause the signal $S(t)$ to deviate from an ideal expression of the form $A_1 \cos(\omega_R t + \varphi(t) + \zeta_1)$, where A_1 and ζ_1 are constants, ω_R is an angular frequency difference between the two beams, and $\varphi(t) = nk\tilde{L}(t)$, with $k = 2\pi/\lambda$ and λ equal to a wavelength for the beams; and

an electronic processor which during operation receives the interference signal $S(t)$ from the interferometry system, calculates a quadrature signal $\tilde{S}(t)$ based on the signal $S(t)$, and calculates an estimate for the coefficients representative of the one or more errors based on the signals $S(t)$ and $\tilde{S}(t)$.

54. A lithography system for use in fabricating integrated circuits on a wafer, the system comprising:

a stage for supporting the wafer;

an illumination system for imaging spatially patterned radiation onto the wafer;

a positioning system for adjusting the position of the stage relative to the imaged radiation; and

the apparatus of claim 51, 52, or 53 for monitoring the position of the wafer relative to the imaged radiation.

55. A lithography system for use in fabricating integrated circuits on a wafer, the system comprising:

a stage for supporting the wafer; and

an illumination system including a radiation source, a mask, a positioning system, a lens assembly, and the apparatus of claim 51, 52, or 53,

wherein during operation the source directs radiation through the mask to produce spatially patterned radiation, the positioning system adjusts the position of the mask relative to the radiation from the source, the lens assembly images the spatially patterned radiation onto the wafer, and the apparatus monitors the position of the mask relative to the radiation from the source.

56. A beam writing system for use in fabricating a lithography mask, the system comprising:

a source providing a write beam to pattern a substrate;

a stage supporting the substrate;

a beam directing assembly for delivering the write beam to the substrate;

a positioning system for positioning the stage and beam directing assembly relative one another; and

the apparatus of claim 51, 52, or 53 for monitoring the position of the stage relative to the beam directing assembly.

57. A lithography method for use in fabricating integrated circuits on a wafer, the method comprising:

supporting the wafer on a moveable stage;

imaging spatially patterned radiation onto the wafer;

adjusting the position of the stage; and

monitoring the position of the stage using the method of claim 1, 32, or 37.

58. A lithography method for use in the fabrication of integrated circuits comprising:

directing input radiation through a mask to produce spatially patterned radiation;

positioning the mask relative to the input radiation;

monitoring the position of the mask relative to the input radiation using the method of claim 1, 32, or 37; and

imaging the spatially patterned radiation onto a wafer.

59. A lithography method for fabricating integrated circuits on a wafer comprising:

positioning a first component of a lithography system relative to a second component of a lithography system to expose the wafer to spatially patterned radiation; and

monitoring the position of the first component relative to the second component using the method of claim 1, 32, or 37.

60. A method for fabricating integrated circuits, the method comprising the lithography method of claim 57.

61. A method for fabricating integrated circuits, the method comprising the lithography method of claim 58.

62. A method for fabricating integrated circuits, the method comprising the lithography method of claim 59.

63. A method for fabricating integrated circuits, the method comprising using the lithography system of claim 54.

64. A method for fabricating integrated circuits, the method comprising using the lithography system of claim 55.

65. A method for fabricating a lithography mask, the method comprising:

directing a write beam to a substrate to pattern the substrate;

positioning the substrate relative to the write beam; and

monitoring the position of the substrate relative to the write beam using the interferometry method of claim 1, 32, or 37.